Soil characteristics in a bottomland hardwood forest five years after hydrologic restoration

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Abstract

The hydrology of the bottomland hardwood forest in Central Ohio was restored in the spring of 2000 by the creation of four breaches in the protective levee along the Olentangy River. A 2005 study was conducted to characterize water content, bulk density, soil color, and total organic content of soils near two of the breaches in relation to elevation, and to compare to previously collected pre and post hydrologic restoration studies. The percentage of hydric soils in the floodplain study areas was 60%, comparable to data collected in 2003. Samples collected in upland areas of higher elevation displayed lower organic content and higher chroma values consistent with areas receiving minimal flooding and non-hydric conditions. Samples collected at the northern breach demonstrated soil characteristics consistent with more frequent flooding than those of the southernmost breach. Average total organic matter content for this area was 9.39 ± 1.77 %, compared to the southern breach average of 6.13 ± 0.53 %. This difference was attributed to variation in flooding patterns between the northern and southern sections of the forest.

Introduction

Bottomland hardwood forests are recognized as an important feature of the landscape, joining riverine systems with upland forests, and function as areas of filtration for nitrates and phosphorus (Mitsch and Gosselink, 2000). These areas also function as exporters of organic matter to the river system during wet periods (Peterjohn and Correll, 1984). Riparian systems such as bottomland hardwood forests experience periodic flooding from adjacent river systems. This fluctuating hydrology regime imparts unique characteristics to these landscape features, allowing the occurrence of both anaerobic and aerobic processes to occur. Floodwaters also serve to exchange nutrients between forest and river systems (NRC, 2002). Unique and diverse vegetation occur in riparian forests, as many of the species found are adapted to periodic flooding and unique soil environments.

The 5-ha bottomland hardwood forest located at The Ohio State University's Olentangy River Wetland Research Park was isolated from the Olentangy River for approximately a century by an artificial levee (Mitsch and Zhang, 2004). In the spring of 2000, four breaches were created in the levee to restore the hydrology of the bottomland system.

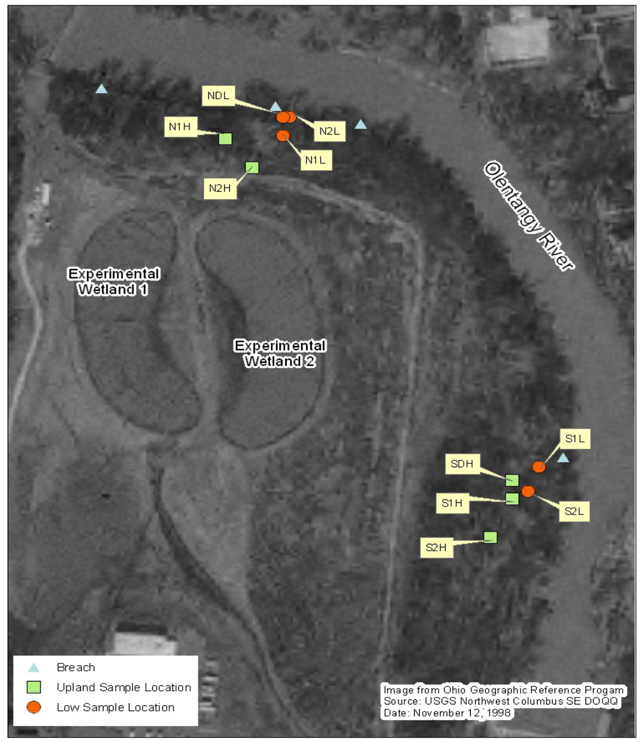

Figure 1: Map of Olentangy River Wetland Research Park showing sampling locations. Breach locations are denoted as light triangles.

This has created a unique opportunity to study the earliest stages of ecosystem development in a restored bottomland hardwood forest. Under the subsidy-stress concept, the frequency, duration, and time of flood events play a large role in the development of riverine ecosystems and their productivity (Odum et al., 1979). It is therefore necessary to understand the soil condition of the restoration area as a function of exposure to floodwaters, and the impact soil condition has on the development of the restored ecosystem. In this study, soil color, bulk density, water content, and total organic matter as a function of location and elevation were examined and compared to previous pre and post restoration soil studies of the area.

Methods

Soil samples were collected at the second and southernmost levee breaches of the bottomland hardwood forest. At each sampling site, samples were collected in low-lying (floodplain) areas of similar elevation to the bank of the Olentangy River and in areas approximately 1 m above the elevation of the riverbank (upland), excluding upland sites that were clearly remnants of the levee. The samples were not collected in a transect pattern but were collected based on the local topography of each breach area, taking several samples at both lower and higher elevations relative to the riverbank. The Global Positioning System (GPS) coordinates of each sampling location overlain on an aerial map of the area are shown in Figure 1.

Soil samples were taken near the second and southernmost levee breaches (Figure 1) using a 2 cm diameter stainless steel soil auger. Samples in which volume was lost or approximately 20 cm of soil could not be collected were rejected and re-sampled. Upon collection of a full sample, the sample depth was measured and recorded. Each core was then cross-sectioned with a knife and compared to a Munsell color chart to determine the hue and chroma of each sample (Munsell Book of Color, 1976). All samples, including the portions removed during color analysis, were placed in sealed plastic bags and stored in a cooler for future analysis. At both the northern and southern breach locations, 10 samples were collected. This includes 2 duplicate samples collected at each area to add statistical weight and relevance to calculated values and to ensure correct methodological reproduction. Upon successful collection of a full sample, the coordinates of each sample location were recorded with a GPS unit.

Tins of soil samples were weighed prior to drying in an oven at 105° C for a 24-hour period. At the end of this period, the samples were re-weighed and moisture content as a percentage of mass lost from the original sample was calculated (Gardner, 1986). The volume of each soil core sample was calculated from the cross-sectional area of the sampling probe and the total length of the collected soil core. Bulk density was calculated by dividing the mass of the dried samples by the initial, calculated volume of the core sample (Blake and Hartge, 1986).

Total organic matter content was determined by mass loss on ignition at 550°C (Nelson and Sommers, 1982). Soil samples dried at 105°C were crushed and sieved, and weighed subsets of each sample were placed in pre-weighed crucibles. Subset weights were approximately 2.5 g of dried soil. Samples were then placed in a muffle oven at 550°C for approximately 4 hours, cooled, and weighed. Total organic matter content was calculated as the percent loss of mass from the original, pre-ignition mass.

Results and Discussion

Soil Color

The Munsell color index data for all soil samples collected during this study are shown in Table 1. Samples collected at elevations of approximately 1 m above the level of the riverbank (high elevation) demonstrated a median chroma of 4. Additionally, none of the samples collected during this study at upland locations demonstrated hydric soil status. This is likely due to the minimal exposure to flood waters that these areas experience. Those samples collected at low elevations and subject to more frequent flooding had median chroma values of 2. Of these low elevation samples, 60 % had chroma values of 2, indicating hydric conditions (Mitsch and Gosselink, 2000). In the current study, the core samples collected near the southern breach (S1La, S1Lb) had a distinct color and texture that was similar to sediments found at the bank of the river near the remnants of the levee. These samples had a chroma of 6, and similar chromas were only observed in areas of higher elevation during the course of this study.

Table 1: Munsell Color Chart values of the bottomland hardwood forest soil samples

Sample Location/ Abbreviation	Elevation	Hue	Value	Chroma
Northern Breach				
N1La	Low	10 YR	3	3
N1Lb	Low	10 YR	3	3
N2La	Low	10 YR	2	2
N2Lb	Low	10 YR	2	2
NDLa	Low	10 YR	3	2
NDLb	Low	10 YR	3	2
N1Ha	High	10 YR	4	6
N1Hb	High	10 YR	4	6
N2Ha	High	10 YR	3	4
N2Hb	High	10 YR	3	4
Southern Breach				
S1La	Low	10 YR	3	6
S1Lb	Low	10 YR	3	6
S2La	Low	10 YR	3	2
S2Lb	Low	10 YR	3	2
S1Ha	High	10 YR	4	4
S1Hb	High	10 YR	4	4
S2Ha	High	10 YR	3	3
S2Hb	High	10 YR	3	3
SDHa	High	10 YR	4	6
SDHb	High	10 YR	4	6

Table 2 shows a comparison between the current study and studies conducted in 1997, 1998, and 2003. The study conducted in 2003 showed that 70 % of soil samples demonstrated chromas of 2 or less (Hossler and Mitsch, 2004). The observed differences may result from the subjective nature of the color index method and transect sampling pattern employed in the 2003 study. Prior to restoration, hydric soils were found only in samples collected

Table 2: Comparison of bottomland hardwood forest soil chromas

Year	No. of Samples	Median Chroma	Maximum Chroma	Minimum Chroma	Percent Hydric	Source
1997	15	2	6	2	13	Geist, 1998
1998	28	3	5	2	43	Bouchard and Mitsch, 1999
2003	37	3	3	1	70	Hossler and Mitsch, 2004
2005						
Low Elevation	10	2	6	2	60	Current Study
1 m Elevation	10	4	6	3	0	Current Study

in proximity to the levee (Hossler and Mitsch, 2004). The increase in hydric soils post restoration observed in the 2003 study was not observed in this study. However, the 60 % hydric value obtained for the floodplain samples in this study is similar to the 2003 study. Given the subjective nature of the soil sampling site selection, it is likely that little or no change in the amount of hydric soils present in the bottomland forest occurred between 2003 and the current study, and that hydric conditions have not developed beyond the lower lying areas of the forest that receive frequent flooding. The dataset as a whole is typical for bottomland hardwood forests, showing hydric soils in the lowland areas and non-hydric soils in the upland areas (Mitsch and Gosselink, 2000).

Water Content

Water content of the soil core samples at the northernmost breach in the levee averaged 11.57 ± 5.27 % by mass. No significant difference could be discerned between the water content of the lower elevation samples and those of the higher elevation samples at this location. The water content percent by mass of the southernmost breach samples averaged 10.11 ± 3.22 %. Again, no statistical difference could be determined between samples collected at high versus low elevation. The percent water content by mass for all samples is shown in Figure 2.

The water content percentages determined in this study represent soil conditions from an average or slightly below average period of early autumn precipitation, based on climate data for the months of September and October of 2005. In October of 2002, water content data was collected during a study of the invasive species Lonicera maacki in the bottomland hardwood forest. This study reported the average water content as 20.9 % (Musson and Mitsch, 2003). Precipitation totals for September and October of 2002 were 11.1 and 6.8 cm, respectively. These values are 4.6 cm above normal for that time of year (NWS). It is therefore likely that the 2002 study reported water content percentages that were elevated due to greater than normal levels of precipitation. Monthly precipitation totals for the current study (September and October 2005) are 7.4 and 3.4 cm, respectively, less than 1 cm below normal for those months (NWS).

Bulk Density

A significant difference in bulk density between the northern and southernmost breach locations cannot be shown within experimental error (Figure 3). Significant variation between samples collected at upland versus floodplain locations cannot be shown in samples collected at the northern breach, but can be shown in the southern samples. Those samples collected at lower elevations have an average bulk density of 1.00 ± 0.11 g cm^{-3}, and those collected at higher elevations have an average bulk density of 1.24 ± 0.11 g cm^{-3}. This difference can be attributed to the nature of the soil in the lower lying areas of the southern breach, which resemble closely the sandy texture and color of the sediment material found at the river bank and in the soils very close to the river, indicative of sedimentation processes occurring in these areas during periods of

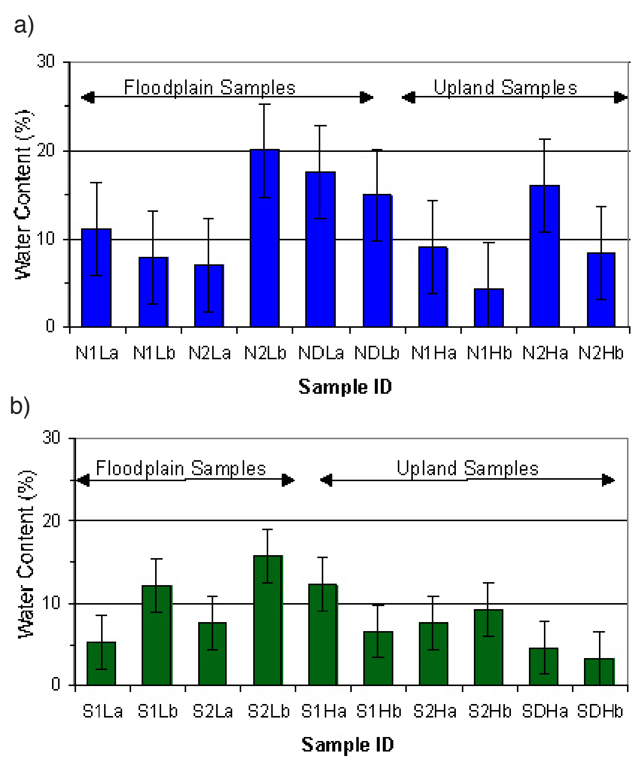

Figure 2: Percent water content by mass of (a) northern and (b) southern breach samples.

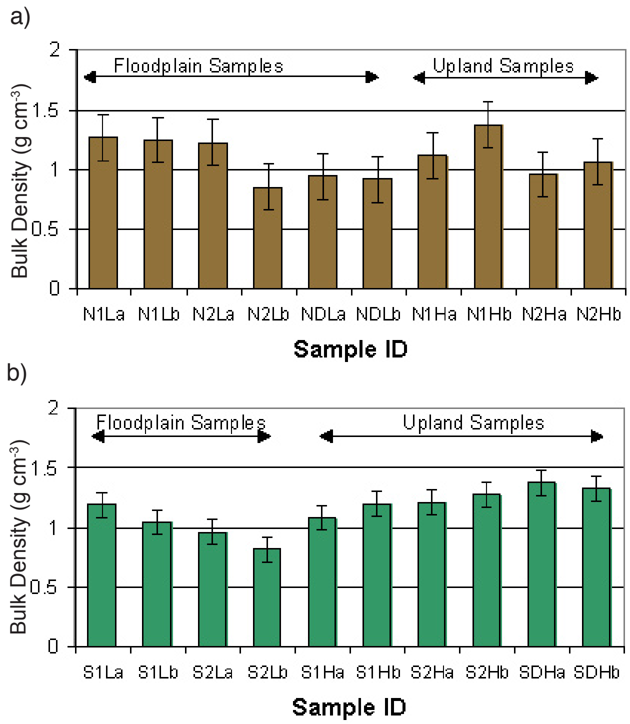

Figure 3: Bulk densities of (a) northern and (b) southern breach samples, calculated as grams dry mass per cubic centimeter.

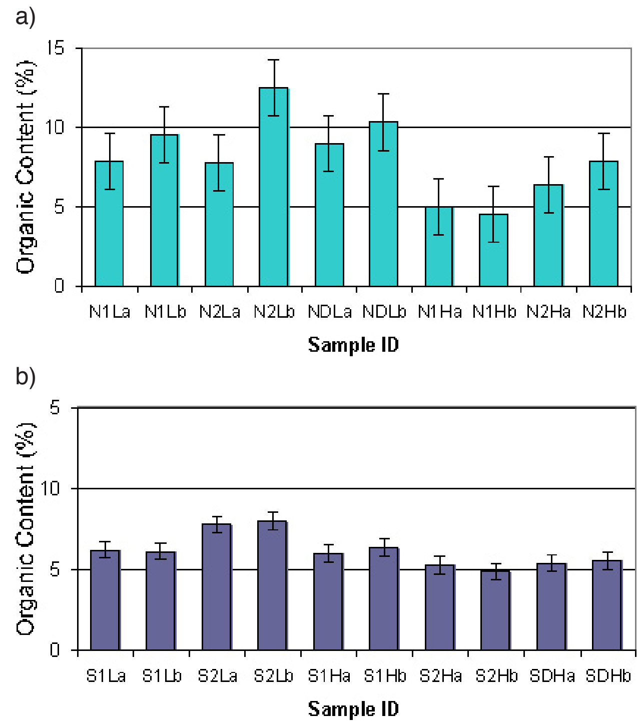

Figure 4: Total organic matter content of (a) northern and (b) southern breach samples, calculated as percent mass lost on ignition at 550° C.

flooding. A 2005 study on the impact of sedimentation on fine root development in riparian forests demonstrated that sedimentation rates as low as 0.3 cm yr^{-1} can significantly decrease the productivity of fine roots (Cavalcanti and Lockaby, 2005). Fine roots are defined as non-woody roots, between 1 and 5 mm in diameter, and are typically associated with under story vegetation in forest ecosystems (Nadelhoffer and Raich, 1992). As organic matter content plays a large role in the bulk density of a soil, it is possible that impeded below ground productivity and fine root development may contribute to the elevated bulk densities observed in the floodplain areas of the southern breach.

Total Organic Matter Content

Total organic matter content determined by percent mass lost on ignition at 550°C is shown in Figure 4. Samples collected at the northern breach averaged 9.39 ± 1.77 %, and those collected near the southern breach averaged 6.13±0.53%, ignoring duplicate samples. A possible explanation for this difference could be leaf letter production. However, in 1999, a study of leaf litter production in the bottomland hardwood forest demonstrated that litter production was significantly greater in the southern sampling sites (Cochran and Bouchard, 2000). These data are shown in Figure 5. A 2004 study of litter production in the same area demonstrated negligible variation in production between the northern and southern sections of the forest (Anderson and Mitsch, 2005). Therefore, it is hypothesized that local variations in floodwater accumulation between the northern and southern breach locations is the cause of the observed difference in organic matter content, and not a result of variation in leaf litter production. Northern locations experience extensive visible pooling of floodwaters, while southern locations experience limited pooling, isolated primarily in channel-like depressions (Mitsch and Zhang, 2003). It has been suggested that decomposition of organic matter is optimized in riparian forests by cycling wet and dry periods, and that decomposition rates are lower in areas that are permanently flooded or experience cycles of aerobic and anaerobic conditions (Brinson, 1981; Lockaby et al., 1996). It is possible that the localized pooling observed in the northern areas of the forest have established a condition of alternating aerobic and anaerobic cycles, thus impeding decomposition and elevating organic matter content.

In both data sets, the upland samples show lower values of total organic matter, 5.46 ± 0.98 %, than the average for the entire area. Regardless of area or elevation, organic matter content of the entire sample set averaged 7.09 ± 2.06%. Organic matter content below 20 to 35 % is indicative of a wetland mineral soil (Mitsch and Gosselink, 2000). Note that all samples with chromas of 2 had total organic matter content percentages greater than the average of the entire dataset, 7.09 % by mass, indication of a positive correlation between exposure to flood waters, hydric soil status, and elevated organic matter content in this bottomland forest.

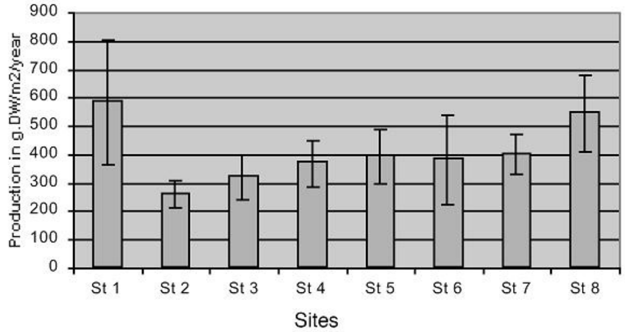

Figure 5: Leaf litter production values from 1999 (Cochran and Bouchard, 2000). Site 2 was used for comparison with the northern breach, and Site 6 was used for comparison with the southern breach.

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